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## Optimization of regional passenger bus traffic network

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### Abstract

An approach to solving of optimization problems of inter-municipal passenger bus transportation routes network based on the development of a regional standard of service quality and the system of principles of its designing is proposed. A model of passenger traffic is discussed. Defining of network is based on the formation of a feasible set of route variants with choosing their optimal combination. The method and the indicators for quality rating of a route network are proposed.

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### 1. Introduction

Development of inter-municipal and interurban civil passenger traffic system is one of the basic social state policy directions providing realization of strategic objectives of population life quality improvement and consumer market development. Solution to the given objectives promotes Russian common economic space formation providing increase in population travel behavior, goods and services consumed quantity with purposeful sustainable development of transport infrastructure focused first on civil passenger traffic service. Formation process of regional passenger motor traffic system network is mainly guided by achievement of social purposes, such as:

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- providing high level of population mobility;
- elaboration and application of effective state regulation mechanisms of transport functioning and development;
- development of transport services competitive market;
- maximization of home demand that is the main source of economic growth and expansion of region territory transit possibilities as foreign income source;
- social-territorial fairness considered as guarantee of transport availability of social benefits to population, as well as free time saving;
- decrease in degree of uncertainty (risk) of economic activities regarding the part that depends on transport factors. Besides unit cost reduction of time for trips, especially passenger ones, is important;
- increase in transport security.

Important direction of realization of the said purposes is forming effective inter-municipal passenger bus transportation routes network providing normative consumer service level guaranteed by service quality standards.

Regional passenger motor traffic system study shows that analyzing travel behavior and volumes of civil passenger traffic it is necessary to consider the following factors:

- population in route populated localities;
- demographic structure of route populated localities;
- availability of manufacturing enterprises and number of people occupied in them;
- availability and sizes of large medical, educational, sports, entertainment complexes;
- population income level;
- employment level;
- distance between populated localities.

## 2. Method

To estimate importance degree of the said factors public opinion poll of inhabitants of some municipal areas aimed at analyzing respondents' movement motives in use of passenger motor transport means of enterprises-carriers was conducted in the Republic of Tatarstan. Poll covered not only motives, but also data on respondent's age, income (indirectly) and employment.

The basic conclusion received from poll results analysis is above all that passenger traffic by inter-municipal bus routes is method providing communication based on social movement motives as opposed to urban routes that are connected with work places, sales areas or social service places.

Statistical analysis of materials, as well as expert evaluation show that such significant at first sight travel behavior factors as:

- demographic structure of population,
- income level;
- employment level

do not play a crucial role in determination of perspective passenger traffic volumes of inter-municipal routes.

So, when income increases basic trip motives are above all:

- assistance to relatives;
- trips to shopping centers and sales outlets for the purpose of foodstuff and industrial goods acquisition;
- increase in educational level,
- trips to recreation centers (garden-plots, summer residences), etc.

Unemployment level in this or that populated locality and presence of manufacturing enterprises in nearby populated localities are not unconditional factors of increase in travel population behavior as well.

Depending on circumstances they can either promote, or counteract formation of bus route traffic flow.

Substantial and situation analysis of abovementioned factors b-f of population travel behavior testifies on the one hand to an ambiguous orientation of their action, and on the another hand to weak degree of influence on civil passenger traffic volume.

As a whole, statistical study results show that among the great variety of factors (motives) influencing population travel behavior and formation of perspective inter-municipal passenger bus traffic volume *population in route populated localities and distance between them* are key factors. Conclusions made confirm in particular world experience of passenger traffic volume modeling as well.

It eventually allows forming bases of statistical model forecasting inter-municipal civil passenger traffic volume. Model construction possibility is caused by initial statistical data (sampling) that are representative by volume and composition and include supervision system characterizing population size of route populated localities, distances between them and real traffic volumes in analyzed period of time.

Data on all available inter-municipal routes of analyzed region municipal areas for a number of years is used as statistical analysis basis of existing passenger bus traffic system. It is necessary to notice that real passenger traffic volumes ( $Q_{ij}$ ) take into account the whole movement motive spectrum.

Travel behavior major factors in inter-municipal passenger traffic model are marked in the following way:

- 1) Distance between populated localities -  $R_{ij}$
- 2) Population size at a starting route populated locality -  $P_i$
- 3) Population size at a terminal route populated locality -  $P_j$

Perspective traffic volume as function  $F$  will be defined by the following equation:

$$Q_{ij} = F(R_{ij}, P_i, P_j)$$

Analysis of available data in the Republic of Tatarstan showed that two model types – linear additive and multiplicative ones – are the most reliable and credible. The multiplicative model is notable for higher reliability level and higher degree of conformity to actual data as corresponding numerical evaluations show.

The conducted study of about 300 model equations showed that most adequate equation type is the following one:

$$Q_{ij} = k \frac{P_i^a \cdot P_j^b}{R_{ij}^c} \quad (1)$$

Model parameter values are defined on the basis of regression analysis. For example, the model overall equation of expected volume of inter-municipal traffic routes of more than 50 km for southeast of the Republic of Tatarstan is the following:

$$Q_{ij} = 53,727 \frac{P_i^{0,337} \cdot P_j^{0,426}}{R_{ij}} \quad (2)$$

Where  $Q_{ij}$  – expected annual traffic volume (thousand people),

$P_i$  – Population of  $i$ -th starting route populated locality (thousand people),

$P_j$  – Population of  $j$ -th terminal route populated locality (thousand people),

$R_{ij}$  – Distance between them (km).

Reliability of the given regression equation is estimated by approximately 90 %, the importance of

regression equation coefficients – from 84.8 % to 99.6 %. The relative approximation error makes up no more than 26.1 %. Consequently, equation (2) can be practically used for perspective traffic volume evaluation both for existing and estimated routes of the given region.

The equation of model (1) is applicable with the same adequacy degree both for inter-municipal routes of more than 50 km and for suburban routes and routes of less than 50 km. Taking into account this circumstance, parameters of the given model for corresponding routes are defined. Then the model for distances of up to 50 km can be used to design routes that are used for transportation of rural area inhabitants to transfer points of long-haul routes.

Suitability of the inter-municipal route model equation for calculation of suburban route traffic volumes is also based on transportation condition and character similarity with the main difference of vehicle capacity and quality of a transport route that is more often inferior to inter-municipal one. Thus, by means of the given model equation it is possible to count civil passenger traffic volumes both for inter-municipal and suburban routes.

To calculate expected traffic volume for a year  $t$ :

- starting and terminal route populated localities ( $i$ -th and  $j$ -th pair) are set; they are usually centers of municipal areas or a region administrative centre for inter-municipal routes;
- according to official data or self-contained estimate approximate perspective population size for a year  $t$  in the long term  $P_i^t$  and  $P_j^t$  is set;

- distance between points ( $i, j$ )  $R_{ij}$  of an existing highway network is defined;

- perspective traffic volume per year  $t$  is calculated on the basis of the formula (2).

The model equation allows to give approached rough passenger traffic volume value of a perspective route accurate within thousand persons of inter-municipal highways. Calculations should be better performed centrally in a central agency or a ministry due to their complexity and labour-intensiveness.

Designing of the whole route network is based on development of separate routes. It begins with determination of starting and terminal route populated localities ( $i, j$ ) that is carried out by developers on the basis of available route network operation experience and practice. Taking into account inter-municipal route character, the given localities are usually municipal area centers and a region administrative centre.

For the set localities according to model equation (2) the perspective civil passenger traffic volume  $Q_{ij}$  is calculated.

**The variant of a route highway** (hereinafter referred to as “**a route variant**”) that includes a list of localities through which highway passes and distances between them is chosen. Number of variants, highway routes is not previously limited.

Total length of a route variant  $R_{ij}$  or  $L_M$  is calculated. Total population size value of localities through which route passes  $N_M$  is calculated.

Variant can be defined manually or by computer generation and the subsequent search of variants of a highway between localities ( $i, j$ ). For this purpose the authors has developed the computer route highway formation program by set starting and terminal route populated localities and a transport network, and also compared existing routes with the assumed ones.

In the course of variant designing the persons that develop route network fragments for the set territories inevitably has to choose the best route variant from locality  $i$  to locality  $j$ . It leads to necessity of deciding the private estimate task of multicriterion choice (integrated evaluation (rating) determination of each of route variants with choice of a route possessing the maximum evaluation).

**I. Initial indices** of route variant determination are:

- 1) Conducted calculation result of perspective route traffic volume  $Q_{ij}$  or  $Q$  that considers traffic both in forward and backward directions ( $Q_{forward}, Q_{backward}$ ).
- 2) Route length  $L_M$  (or  $R_{ij}$ ).
- 3) Size of population that live in all populated localities through which route passes  $-N_M$ .

**II. Parameters**, values of which are determined by regulatory values used during calculations, are:

- 1) Tariff of one passenger kilometers -  $\tau$
- 2) Calculation parameter of average passenger trip distance  $\epsilon$
- 3) Costs (expenses) per unit for 1 kilometer done  $S_{KM}$
- 4) Capacity of a vehicle used for traffic according to the given variant  $Q$ .
- 5) Accepted value of statistic factor of vehicle capacity use  $\gamma$
- 6) Loaded kilometrage proportion  $\beta$

Parametre  $S_{KM}$  includes not only operation costs, but also a share fallen to drivers' salary adjusted for taxation, as well as a share fallen to overhead expenses.

**III. The following indices are calculated** in route variant evaluation:

- 1) Average passenger trip distance of the given route  $L_{av.}$
- 2) Passenger turnover of the given route  $P$
- 3) Travel population behavior of the route  $B$
- 4) Total kilometrage of the route  $L_{TOTAL}$
- 5) Income of the route  $D$
- 6) Expenses of the route  $C$
- 7) Profitability of the route  $R$

The chosen route quality evaluation indices are calculated on the basis of parameter values (1) – (6) set at the previous stage. The following calculation stage sequence is provided:

- 1) Average passenger trip distance calculation

$$L_{av.} = L_M^\epsilon,$$

Where  $L_M^\epsilon$  is route length to the  $\epsilon$  power

- 2) Passenger turnover calculation of a route

$$P = L_{av.} \cdot Q = L_M^\epsilon \cdot Q$$

- 3) Travel population behavior calculation

$$B = \frac{Q}{N_M}$$

4) Expected income calculation of a route

$$D = \tau \cdot P$$

5) Calculation of route expenses (has auxiliary value, is not considered during optimum variant choice)

$$C = s_{km} \cdot L_{TOTAL} \cdot q$$

6) Route profitability calculation

$$R = \frac{D - C}{C} \cdot 100$$

Routing experience problem solving for the Republic of Tatarstan shows that:

- 1) Loaded kilometrage proportion  $\gamma$  for interurban and inter-municipal routes is usually within the range of 0.7-0.99.
- 2) Parameter  $\epsilon$  is usually within the range of 0.8-0.9.
- 3) Parameter  $\tau$ ,  $s_{km}$  are calculated taking into account existing civil passenger traffic peculiarities of an analyzed region.
- 4) Parameter  $\beta$  is usually within the range of 0.950-0.999

Parameter  $q$  characterizing capacity of vehicle type intended for traffic of the given variant is used as the basic variability regulator. Each vehicle type has its own value of costs per unit for 1 kilometer done  $s_{km}$ . Setting various vehicle types for route service allows varying values of variant quality evaluation indices.

Average passenger trip distance value ( $L_{av.}$ ) should correspond to specifications of regional quality standard of service. In the standard of the Republic of Tatarstan, in particular, it is noticed that:

- 1) For interurban service routes depending on route length:
  - When route length is 100-200 km:  $L_{av.} = 60-70$  km.
  - When route length is 200-300 km:  $L_{av.} = 90-100$  km.
  - When route length is 300-400 km:  $L_{av.} = 140-150$  km.
  - When route length is 400-500 km:  $L_{av.} = 190-200$  km.
  - When route length is 500 km and more:  $L_{av.} = 250-300$  km.
- 2) For suburban service routes  $L_{av.} > 8 \div 12$  km.

Travel population behavior index value of a route  $B$  should correspond to regional standard specifications of the Republic of Tatarstan that, in particular, constitute:

- 1) Quality index  $B > 5 \div 10$  – for municipal and inter-municipal network in interurban service.
- 2) Quality index  $B > 60 \div 80$  – for a municipal and inter-municipal network in the suburban service.

In case values of the given indices of a designed route do not correspond to the specification, the variant is rejected.

The task of choosing an optimum route variant among set alternative ones is reasonable to solve on the basis of multicriterion optimization method use (multicriterion tasking). Choice multicriteriality is caused by availability of three antagonistic choice purposes – achievement of maximum satisfaction of population needs in traffic, movement comfort and safety and maximum profit-making.

If you use multicriterion decision-making tasks (MCDMT) as:

$$\{X, R_1, R_2, \dots, R_j, \dots, R_m\}, \quad (3)$$

where  $X = \{x_i, i = 1, 2, \dots, n\}$  – set of alternatives,

$R = \{r_j, j = 1, 2, \dots, m\}$  – variety of criteria (purposes),

a formal base of development of recommendations (estimates) may be implemented as follows:

1) Statement of a problem of choice of the appropriate route among the variety of alternative routes according to chosen criteria.

2) Drawing a list of  $m$  criteria  $\{r_j\}$  in the nominal scale ( $r_1$  – meeting demand of the population for the civil passenger traffic,  $r_2$  – profit,  $r_3$  – safety and comfort of transportations etc.).

3) Detection of level of significance (scales) of criteria  $\{w_j\}$ .

4) Drawing a list of  $n$  alternatives  $\{x_i\}$  in the nominal scale.

5) Forming of the table of basic data by display of the variety of  $n$  alternatives on the variety of  $m$  criteria (item 2) in the form of quantitative estimates  $C_{ij}$ .

6) Choice of a method of solution of multicriteria problem (from a perspective of specificity of the original problem it is the most reasonable to use AK&M method with all its methodical advantages and limitations).

7) Receipt of vectors of local and global priorities.

8) Search for the appropriate solution.

When solving the problem of the appropriate network of inter-municipal passenger bus transportation routes of the Republic Tatarstan as the basic criteria indicator the profitability indicator was chosen. It is stipulated by the fact that criteria of transportation safety and social criteria were considered at initial stages of the problem solution when forming of the initial variety of alternatives which was limited by strict specifications of the regional standard which included corresponding indicators-parameters of the problem.

When choosing it is considered that  $m$  alternatives of a route are received which comply with the standard requirements. For each of them the profitability indicator is specified, for  $I$  – variant  $R^I$ , ( $I = 1, 2, \dots, m$ ).

There is a variant with maximum profitability  $R^{\max} = \max\{R^I, I = 1, 2, \dots, m\}$  which is considered to be appropriate.

When the choice of the appropriate variants of routes is finished calculations of general technical and economic indicators of the formed route network are performed.

With  $N$  routes received the calculation of network general indicators includes:

1) Calculation of travel behavior of the population on the set route network (**B**):

$$B = Q_{\text{year}} / N_{\text{pop}}$$

$Q_{\text{year}}$  – annual volume of transportations (pass.);

$N_{\text{pop}}$  – number of inhabitants residing in the network territory (cities, municipalities) (people).

### 3. Conclusions

The indicator of the travel behavior is the basic criterion of quality of forming results of the entire route network. It must meet requirements of the regional quality standard of transport servicing making:

a)  $B > 5 \div 10$  – for municipal and inter-municipal network in intercity traffic.

b)  $B > 60 \div 80$  – for a municipal and inter-municipal network in suburban traffic.

If calculated travel population behavior of the formed network does not conform to standard requirements, received conclusions are considered unacceptable, repeated determination and calculation of route variants and optimum variant choice is carried out.

## 2) Income calculation of a route network

$$D_{MC} = \sum_{i=1}^N D_i,$$

where  $D_i$  is  $i$ -th route network income,  $N$  – number of routes

## 3) Calculation of expenses during route network operation

$$C_{MC} = \sum_{i=1}^N C_i,$$

Where  $C_i$  is  $i$ -th route network income,  $N$  – number of routes

## 4) Profitability calculation of a route network as a whole

$$R_{MC} = \frac{D_{MC} - C_{MC}}{C_{MC}} \cdot 100$$

Comparison of total evaluation indices of the developed route network with corresponding indices of the existing one allows drawing conclusions on its advantages and disadvantages. Application of the offered approach for route network optimization purposes of the Republic of Tatarstan, in particular, has shown that increase in common profitability by 6-7 % is reached with increase in civil passenger traffic volume by 16 % that testifies to approach importance in respect of solution to challenges of effective region bus route system formation.

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